Study of plasma dynamics and spectral tunability in hollow cathode triggered gas-discharge sources

Florian Melsheimer, Malte Ranis, Daniel Wilson, Sophia Schröder and Larissa Juschkin

Experimental Physics of EUV, RWTH Aachen University, Steinbachstraße 15, 52074 Aachen, Germany
Peter Grünberg Institut (PGI-9), Research Centre Jülich GmbH, 52425 Jülich, Germany
JARA Fundamentals of Future Information Technology
Fraunhofer Institute for Laser Technology, Steinbachstraße 15, 52074 Aachen, Germany

Introduction

Gas discharge EUV sources are compact and versatile sources of short wavelength radiation for small-scale applications. The emission of EUV-radiation is based on a high voltage discharge within a low pressure enviroment. Dynamics of the emitting plasma depends strongly on electrode geometry and electrical properties as well as gas pressure and type. This consequently affects the emission spectrum and power as well as temporal and spatial properties of the radiating volume. In order to optimize and tune this type of source for different applications deep understanding of theses correlations is essential. The purpose of this poster is to visualize the most basic effects encountered in this type of EUV-source.

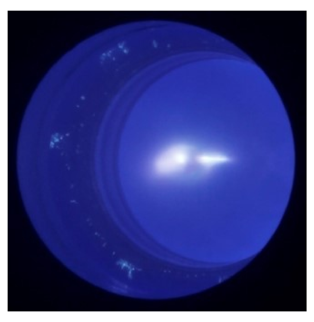


Fig. 1: Time integrated image of an Argon plasma pinch in visible spectrum. The borehole diameter is 10 mm.

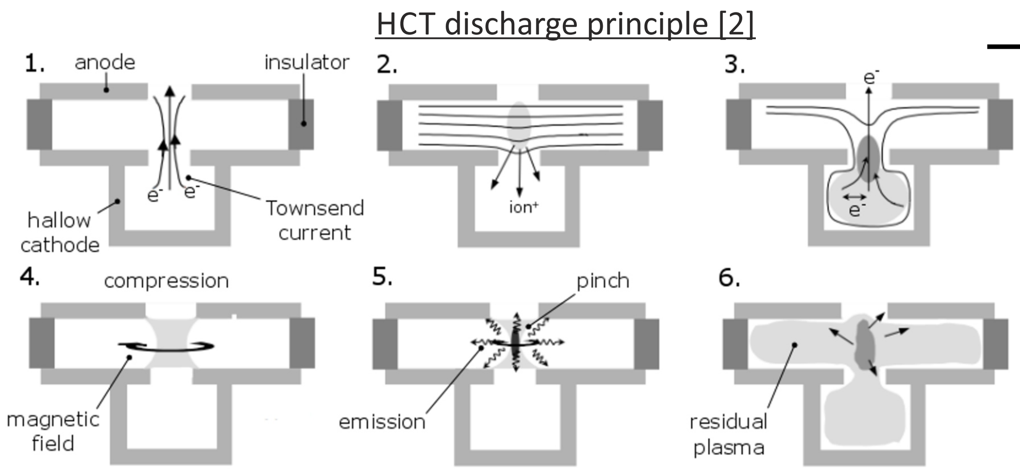
Theory of pseudospark discharge

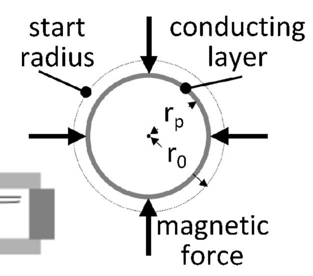
The hollow cathode triggered gas discharge source
operates in pseudo spark regime:

- low pressure (10-100 µbar)
- **mean free path** of atoms > electrode distance
- breakdown voltages of several kV

Discharge process:

- free electrons and ions are accelerated by applied voltage **(1,2)**
- oscillating electrons produce more free charges (HC-phase, **3**)
- conduction at gap starts on a thin shell caused by **skin effect** (**4**)
- lorentz force leads to compression
- more atoms are picked up and ionised/excited (**snowplow model**)
- in pinch phase **(5) kinetic energy of ions** is transferred to electrons
- plasma is further heated by **ohmic losses**
- **dense and hot** (10^{18} cm^{-3}, 35 eV) pinch radiates down to EUV range
- plasma scatters over electrode system **(6)**
- ions recombine





Temporally and spatially resolved measurements

Spectral analysis:

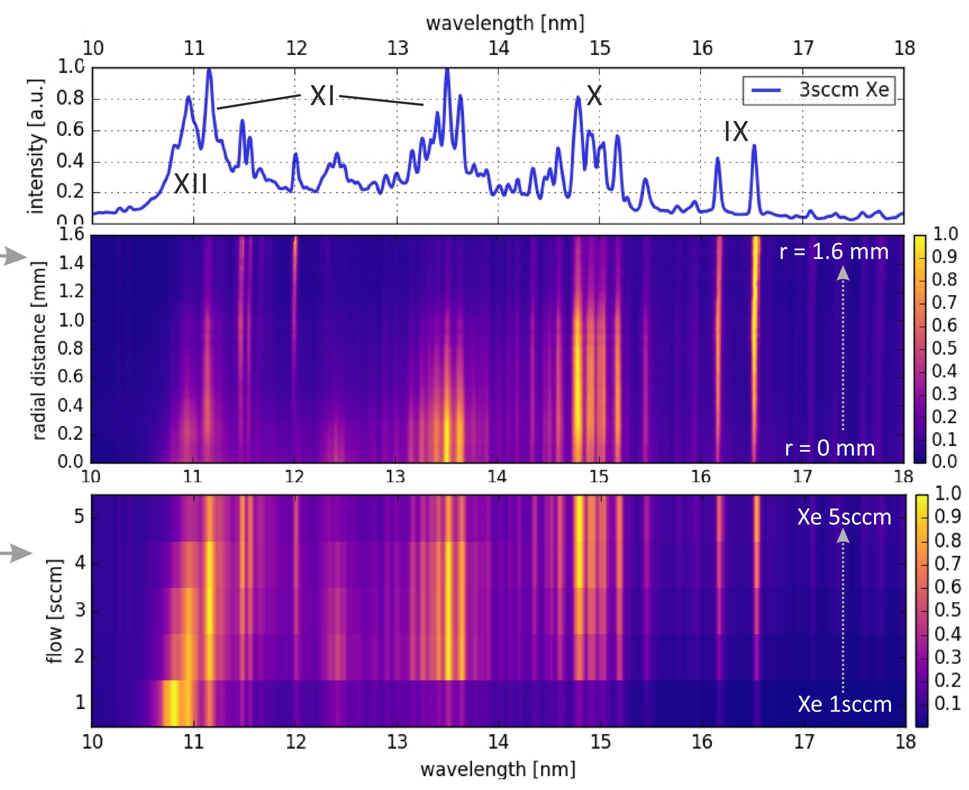
- spatially resolved spectra
- recorded with cross slit setup
- 1:2 magnification, on axis
- each row normalized
  --> **relative intensity** at each radius

Increasing distance from z-axis (r):

- mean ionization level drops
- **colder** plasma on **outside**

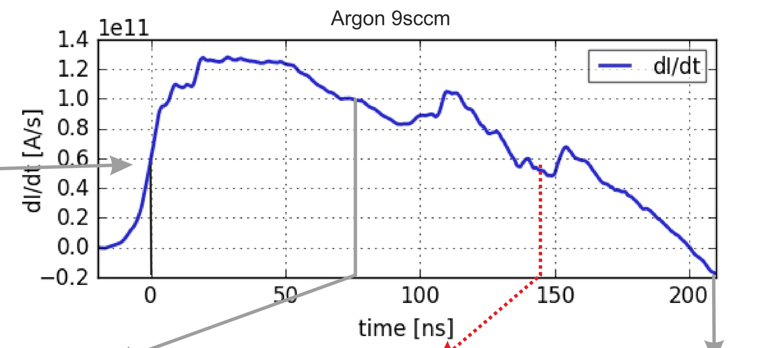
Increasing pressure:

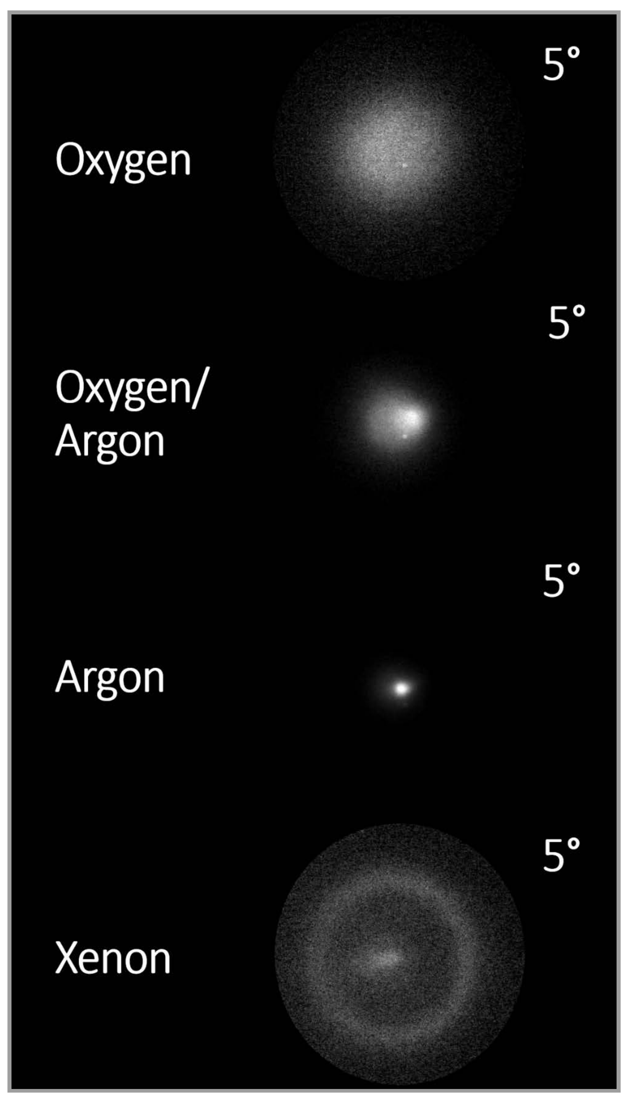
- pressure at gap ≈15-60 µbar
- more gas at same discharge energy
- less energy per ion
- mean ionization level drops
- **colder** plasma at **high pressure**



Time evolution:

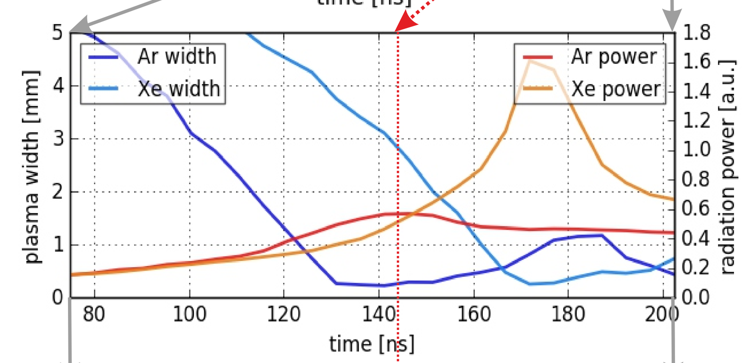
- plasma imaged with pinhole camera (5.1 ns steps)
- **rise of dI/dt** as reference (75 ns min. delay)
- radiation power and plasma distribution analysed:
- strongest **emission** at **highest compression**





Click to play! (flash, use Adobe Reader)
Videos: 200mio. frames/s, same interval for every gas and position.

Gas	max. snowplow speed	minimal diameter	time to compression
Oxygen	60km/s	800µm	105ns
Ar/O	46km/s	480µm	126ns
Argon	42km/s	260µm	146ns
Xenon	48km/s	250µm	172ns

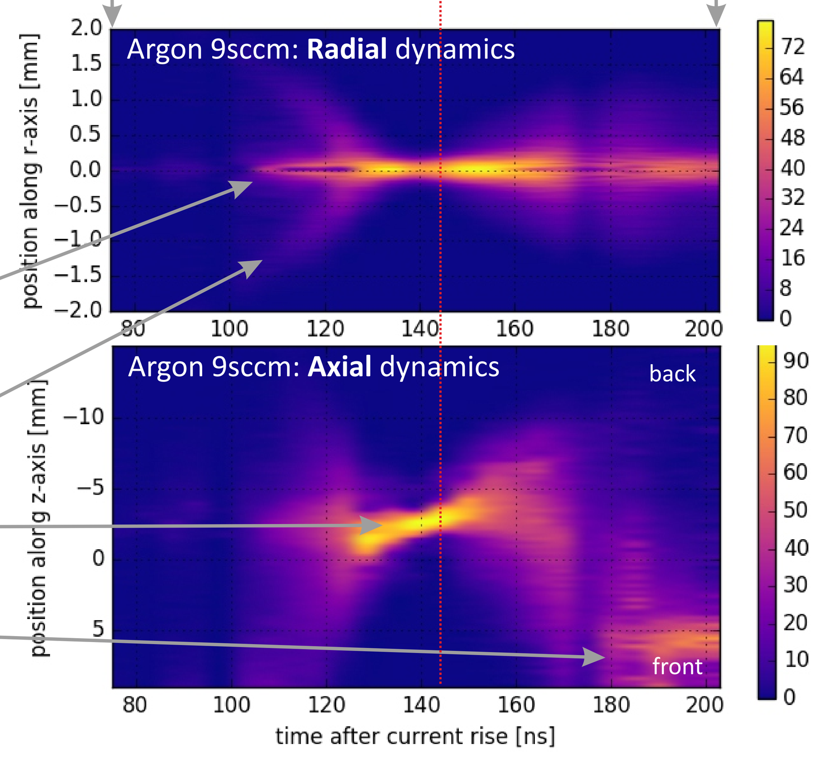


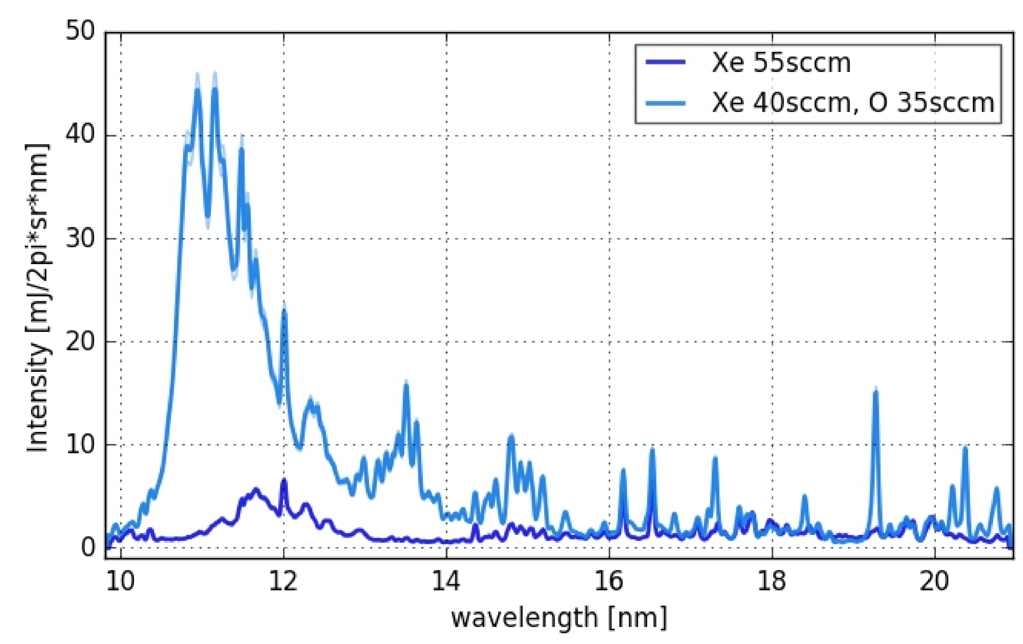
3-d reconstruction

- plasma has axial symmetry:
- **off-axis images** allow full 3D-reconstruction of plasma distribution

Argon discharge at 2.4 kV:

- **ghosting artifact** from reflected gating pulse
- **radial direction:** collapsing snowplow visible (r-axis)
- **during pinch phase:** plasma pinch moves back (z-axis)
- **after pinch phase:** plasma is pushed out to front





Energy calibrated spectrum

Gas mixture:

- high power source with worn electrodes:

Pure Xe:

- limited to 500 Hz
- no output at 13.5 nm

Xe/O mixture:

- stable operation at 2 kHz
- significantly improved output at 13.5 nm

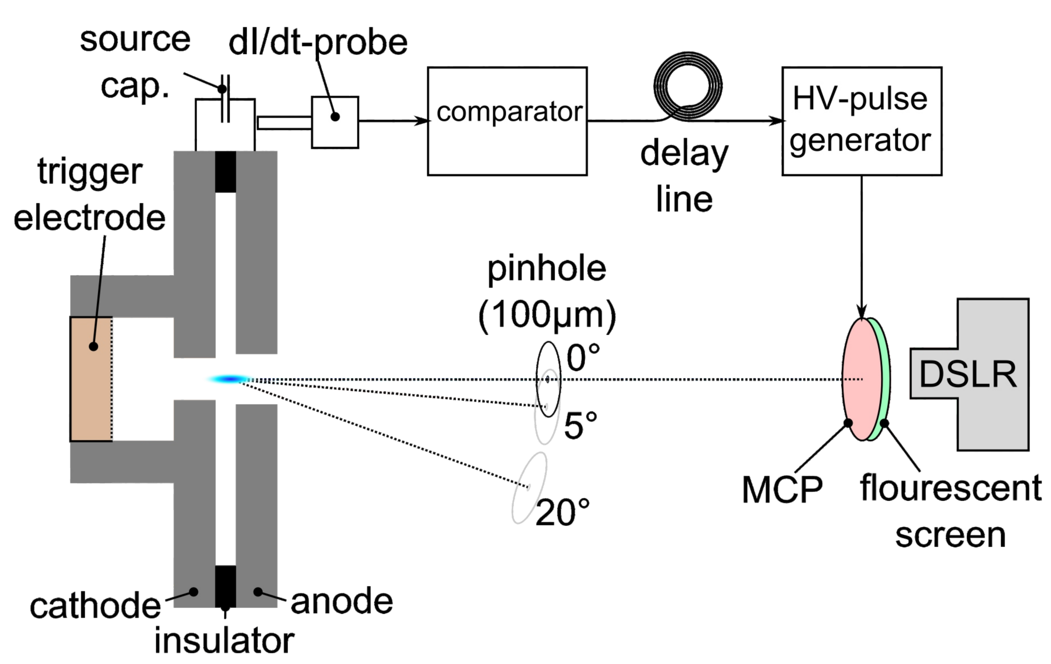
Experimental Setup

Pinhole camera:

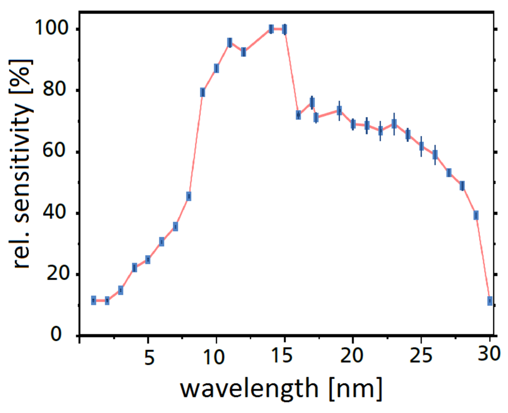
- 100 µm pinhole
- 2-3x magnification
- micro channel plate with caesium iodide coating (CsI)
- **5-30 nm** sensitivity
- **180 µm resolution**
- each frame **averaged over 200 shots**

Synchronization:

- rise of analog **dI/dt-signal** digitalized by comparator
- digital signal delayed by **cable delay line**
- HV-pulser: -1.2 kV at 2 Ohm
- 2 ns pulse length



Relative sensitivity of CsI coated MCP [3]



Outlook

- **eliminate cable reflections** and thus ghosting in MCP images
- **scientific camera** for less noise
- **advanced imaging optics** (mirror, zone plate) for increased flux and resolution
- use imaging and analysis techniques in future experiments (e.g. laser heated discharge palsma)

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